Reliability Means Performance

Three Recommendations for Program Managers

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> **"We can't afford to wait until OT&E [Operational Test and Evaluation] to evaluate system reliability. We need to use system models and testing early enough [before OT&E] to influence the design before changes become too costly."**
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> **—Dr. George Wauer**
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In today's streamlined acquisition environment, multi-functional Integrated Product Teams, or IPTs, are challenged with developing and fielding cutting-edge technology to meet warfighter requirements. Design teams focus on maximizing performance factors such as top speed, max payload, and target accuracy. IPTs are also concerned with system reliability, or the ability of a system to successfully perform its intended function over a period of time. As the debilitating effects of poor system reliability become more evident to system developers they, in turn, place more and more emphasis on system reliability.

Moderate Success to Borderline Disaster

Currently, logistics and supportability IPTs address most issues related to reliability. The effects of addressing reliability within logistics and supportability IPTs generally range from moderate success to borderline disaster. Early fatigue in structures, high failure rates in electronic components, and erratic software performance are just a few component-related problems encountered while fielding new weapon systems.

The seemingly unpredictable nature of reliability stems from a variety of ways IPTs apply the fundamentals of reliability in systems design. Programs that *isolate* reliability engineering to only the logistics IPT (or any other single IPT, for that matter) eventually pay thousands, and even millions of dollars in system repairs, reworks, and component replacements. In essence, this approach may be addressing reliability *symptoms* rather than the *source* of reliability.

On the contrary, programs that *release* reliability from the confines of a single IPT, and address reliability as the result of robust engineering methods experience tremendous success.

Reliability, when regarded as a key performance factor for a system, results in millions of dollars in life cycle cost savings for acquisition programs. This is not to say that logistics and supportability are unimportant to the acquisition process. Logistics and supportability are extremely important to system effectiveness, and are directly affected by sys-

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tem reliability. However, designing for reliability also serves a crucial role in system development, since the *true* source of system reliability rests in robust materials, environmental resilience, redundant system architecture, robust manufacturing processes, and assembly techniques. In fact, similar design characteristics also affect "traditional" performance factors such as payload, max speed, and accuracy.

So why isn't reliability regarded by IPTs in the same light as traditional performance factors? In this article, I propose reliability as a key performance characteristic of a system. I also propose three low-cost recommendations to ensure program managers field reliable systems.

What is Reliability?

Without getting into complex mathematical derivations, let's presuppose a working definition of the term "reliability."

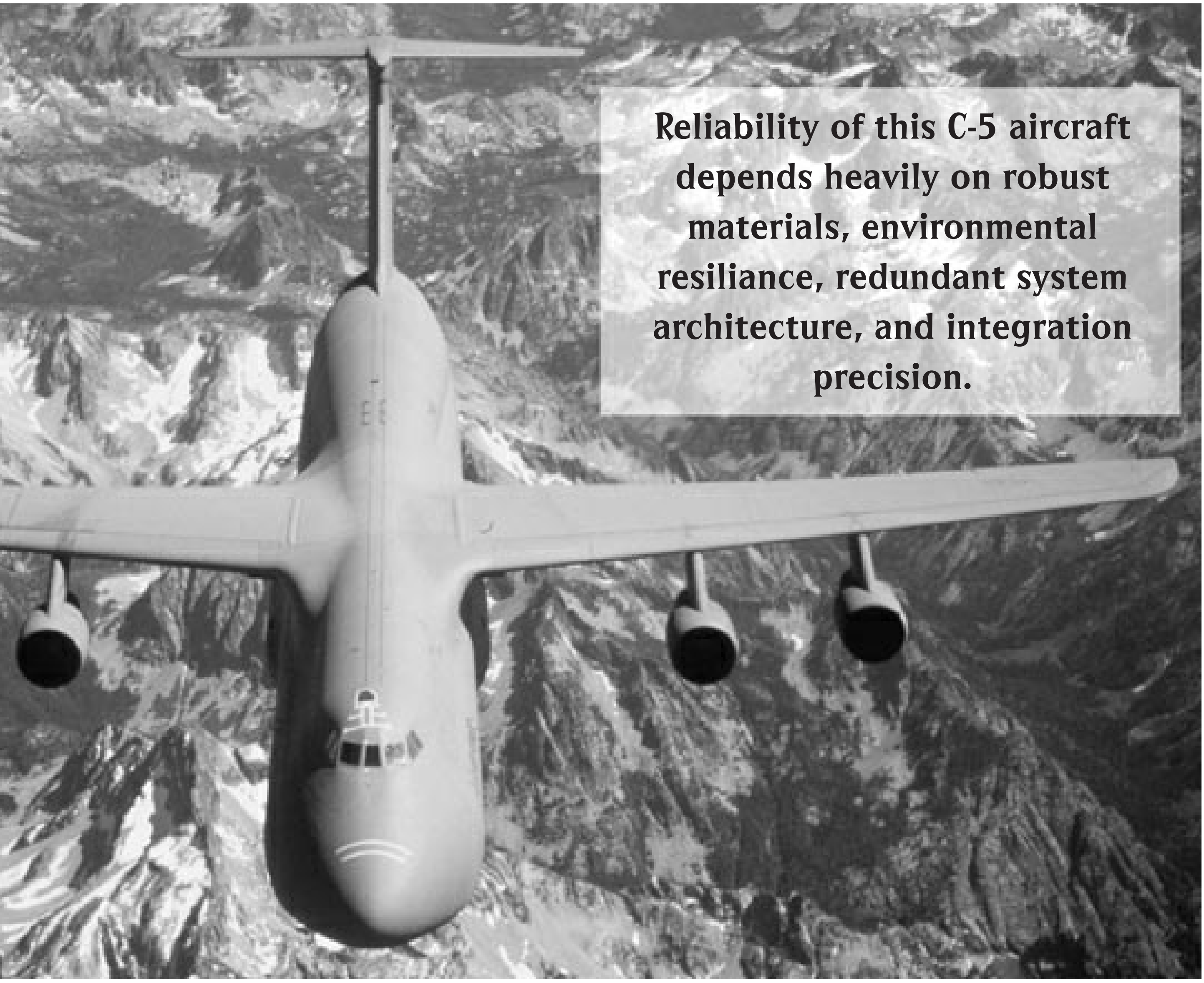
> *The reliability of a system is the probability that, when operating under stated environmental conditions, a system will perform its intended function adequately for a specified interval of time.*

From this definition, we establish reliability as a probability, and a function of time. Further, we can also assume that the reliability of a system deteriorates over a given period of time. Reliability also assumes the identity of probability distributions. One of the more commonly used probability distributions used to model reliability is the exponential distribution, written as:

$$R(t) = e^{-\lambda t}$$

Where R is reliability, λ is 1/(Mean Time Between Failures), and t is time. From the mathematical definition, we see that for an exponential distribution, reliability is a function of time and Mean Time Between Failures, or MTBF. MTBF is defined as the mean time a system will successfully perform its intended function. This is a key parameter used in measuring reliability.

Another concept pertaining to reliability is redundancy. System redundancy



Reliability of this C-5 aircraft depends heavily on robust materials, environmental resiliance, redundant system architecture, and integration precision.

DoD photo by Senior Airman Steve Thurow

is achieved by using multiple subsystem components connected in order to increase reliability. Redundancy can be achieved by using several methods. The first method is achieved by connecting systems in series (Components A-C, bottom chart). In a series system, all individual components must operate if the system is to function. Connecting subsystems in series tends to decrease reliability, since the reliability of the entire system is equal to the product of the individual reliabilities of that system.

A more common method of redundancy is achieved by connecting components in parallel (Components D-F). A parallel system is a system that is not considered to have failed unless all components have failed. Achieving redundancy using parallel systems is a standard practice and generally increases system reliability when more parallel components are added. In system design, a combination of series and parallel systems within the overall architecture is commonplace. In fact, a combination of both types of systems is almost unavoidable. Once systems engineers determine the reliability of individual components, overall system reliability can be empirically calculated.

Sources of Reliability Information

Now that we've reviewed key concepts in reliability, let's explore the methods of determining reliability. At the component level, reliability can be determined from a variety of sources.

Lab

Many component reliability values are determined by operating the component in laboratory environments. In the lab, time-to-failure data are collected and analyzed for possible design improvements. Unfortunately, lab data can sometimes prove to be inaccurate when the component is integrated with another system.

Field

Another source of component reliability is the historical failure rate of components already operating in the field. While this may provide valid data for a given system, the reliability data may prove to be different when the component is integrated with a new system that operates in a different environment (i.e., different temperature, stress level, or number of cycles).

Modeling and Simulation

Other sources of reliability information include mathematical modeling, computer simulation, or performance of similar components. These methods provide early insight into reliability performance, but must be validated with actual field data. But what determines whether a particular component is reliable or unreliable?

True Source

The true source of system reliability rests with the *performance of individual components and subsystems.* Raw materials, structural make-up, complexity, functional characteristics, manufacturing precision, and assembly processes all determine the ability of a system to complete its intended function. In short, the longer a system's components will last, the longer the system will last! Herein lies the rationale for directing reliability practices toward design criteria that traditionally impact other performance areas (i.e., material development, component selection, system architecture, or manufacturing and assembly processes).

So how do IPTs apply reliability in engineering design in order to bring about system improvements? I propose three low-cost recommendations for regarding reliability as true performance criteria in system development.

Recommendation No. 1

Develop a reliability development program early.

If IPTs are to ensure robust system reliability, a comprehensive reliability development program must be established prior to Milestone 0. Form a reliability action design team consisting of reliability engineers, systems engineers, manufacturing engineers, and other applicable engineering disciplines (i.e., structural, human factors, electrical, and aeronautical). Include multifunctional representation from users, program management, contractors, and others. Involve the reliability team in the requirements process, and establish a charter with concrete reliability goals. Develop measurable goals and an overall plan geared toward achieving success.

Recommendation No. 2

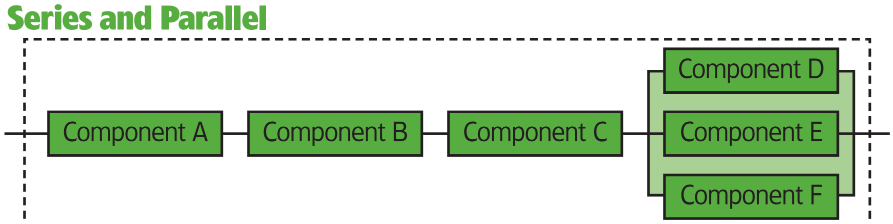
Carry the process further by developing and including reliability goals for major subsystems.

As design teams take ownership of individual subsystems (structures, software, electrical, and controls), these teams should also be responsible for developing subsystem reliability goals and including those values in requirements documentation. The design team should, in turn, report this information to the reliability action team to determine overall system reliability goals.

To meet their reliability goals, the subsystem design team should also concern themselves with subsystem design considerations. Design teams may have to consider one or more of the following factors, and their cumulative impact on subsystem reliability:

- Complexity of the Design
- Raw Material Selection
- Environmental Effects
- Dimensional Tolerances
- Level of Manufacturing Automation and Process Control

Overall System Consisting of Components Connected in Series and Parallel



- Workmanship and Precision Tooling
- Assembly Techniques
- Quality of Off-the-Shelf Components.

Of course, determining how sensitive reliability is to a given design consideration is a challenging undertaking, especially prior to the development of subsystem prototypes. In fact, evaluating initial reliability data is such a difficult task that design teams believe the exercise is non-value-added. To overcome this challenge, the next recommendation proposes a strategy consisting of reliability modeling and validation.

Recommendation No. 3

Develop methods for evaluating reliability goals and validate the methods as the system matures.

At this point, our reliability action team has developed overall reliability goals, subsystem goals, and has made design decisions that will achieve these goals. Should the program manager wait until Operational Test and Evaluation (OT&E) to determine if reliability goals are met? I've attended program meetings where members were convinced that reliability could only be evaluated during or after OT&E. This mindset, although effective at the time, usually results in costly design changes, configuration control problems, poor field reliability, and frustrated users.

On the contrary, effective reliability analysis, modeling, and evaluation can be accomplished *prior* to OT&E, especially when historical reliability data exist on the majority of the components chosen in the design! In today's climate of reduced budgets and downsizing, we can ill afford to wait until OT&E to start reliability test and evaluation. High reliability can be achieved with measurable reliability goals and a progressive plan toward achieving those goals.

During initial design reviews (reviews where raw materials, sub-system make-up, initial architecture, and components are chosen), engineers may use a variety of methods to predict the reliability of sub-systems. For components already developed and in use, research can reveal the historical reliability of components. Field and lab data from other applications can serve as a basis from which to determine component reliability values. Developers must scrutinize environmental operating conditions of components and match these conditions as closely as possible.

Most component manufacturers track failure rates and MTBF information on all of their products. If the component has never been manufactured before, analyze the materials used for the component. Predict the reliability of the new component by researching components manufactured using the same or similar materials.

Once the design team establishes baseline reliability values, they can then report their findings to the reliability action team. This information can be checked against requirements documents in order to predict, with reasonable fidelity, if reliability goals are being met.

Once individual subsystem prototypes are built, laboratory tests can determine if previous reliability predictions are correct. Prior to the tests, design teams should understand all applicable assumptions (realistic number of cycles, environmental conditions, and test unit limitations). If an effective laboratory test cannot be accomplished, team members may have to draw conclusions based upon known data. (Note that at this point no working system prototypes have been built, yet the design team has found independent sources of reliability that can be compared to system reliability goals.)

Once prototype subsystems are fabricated, use the same methods of reliability prediction to determine if reliability goals are met. Software integration laboratories, mechanics laboratories, environmental chambers, and wind tunnels are excellent examples of facilities that can be used to evaluate sub-system reliability. Unfortunately, this type of testing can prove to be costly, given the amount of runs required to produce component failure. Therefore, design teams may opt to calculate their aggregate reliability values using individual component reliability values.

Design teams may also narrow the list of subsystem reliability tests to include only the most critical subsystems. Whatever the subsystem, a method of collecting failure data must be established once prototype developmental testing begins.

Contrary to the traditional viewpoint that reliability testing can only be accomplished during OT&E, initial prototype Developmental Test and Evaluation (DT&E) provides an excellent opportunity to collect failure data. During DT&E, the system is considered immature. Production facilities and manufacturing methods are not yet established. During DT&E, tests demonstrate that specified system requirements are met. So why can't sub-system reliability data be collected?

A case can be made that DT&E traditionally is not long enough in duration to collect statistically significant reliability data. This is a valid point. However, neglecting to collect and track component reliability data would prevent design teams from discovering useful trends. If reliability data are tracked on critical components, trends may be detected that identify potential design improvements. Without a focus on reliability trends, repeat component replacements would be identified in OT&E or after fielding, where design changes and configuration control are more difficult.

Component failure indications during DT&E can also provide clues early in the developmental process in order to make design changes and provide focus areas for OT&E. For example, are soldering processes precise enough for the given failure rate of a component, or will they fail earlier than expected? Are materials robust enough to withstand the environmental conditions? Should OT&E include additional runs in extreme operational environments?

During OT&E, the system is evaluated in order to ensure its operational requirements are met. From a reliability standpoint, sub-system and component MTBF are recorded. At this point, production and manufacturing processes may already be established. Major redesign efforts are complete, and the system performs in its operational environment. Major changes to processes or materials may be infeasible, time consuming, or costly. Attention to reliability performance in earlier phases of development should theoretically reduce the possibility of major redesigns.

Nevertheless, OT&E provides a snapshot of overall system reliability. Frequent subsystem failure rates during OT&E should serve as a sign that reliability will decrease once the system is fielded. Design teams should thoroughly analyze failures, root causes, and their impact once fielded. Hopefully the reliability action team has evaluated the system, and the risk of low reliability after fielding the system is mitigated.

OT&E Is Not the End

Reliability focus does not end with OT&E! Once the system is fielded, the reliability action team should become a permanent part of sustainment activities. The team should identify critical systems and components where low reliability rates prevent mission accomplishment. Further, investigations should be conducted to answer the following critical questions:

- What sub-systems are degrading the quickest?
- What is the root cause (vendor change, new environmental conditions, or component manufacturing processes)?
- What is the corrective action (component replacement, improved manufacturing, or repair)?

System Reliability Synonymous With Performance

The purpose of this article was to propose the release of reliability design practices from the confines of a single IPT, and address the source of reliability performance at the component and subsystem level. Reliability is a viable performance characteristic, with its roots nested in the quality of components, materials, interfaces, workmanship, and manufacturing processes.

The recommendations in this article may bear a sharp resemblance to design activities conducted for "traditional" performance factors of systems. Regarding *system reliability* as synonymous with the term *performance*, program managers will find that total life cycle costs can be reduced by forming an action team dedicated toward achieving robust "reliability performance."

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